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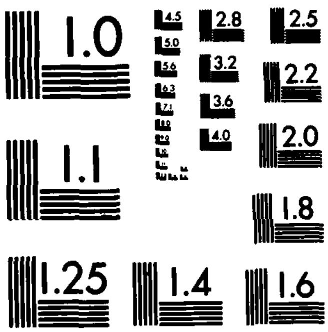

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QUASIPARTICLE HARMONIC MIXING WITH SIS JUNCTIONS

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Abstract

We have demonstrated quasiparticle harmonic mixing of a 36 GHz signal with an 18 GHz local oscillator in tin SIS junctions. Harmonic mixers can have important advantages at high microwave frequencies where insufficient LO power is available.

Introduction

Quasiparticle mixers have been operated at frequencies as high as 230 GHz [1]. Their low noise and high conversion efficiency make them particularly attractive for heterodyne receivers with sensitivities near the quantum limit. Harmonic mixers, in which the local oscillator (LO) frequency is near some submultiple of the signal frequency, can be of practical importance in cases where higher frequency LO power is not readily available. Shen [2] has extended Tucker's three-port quantum mixer calculations [3] to include first harmonic response, although no predictions of conversion efficiency for a harmonic mixer have been published to date. We report here the first measurement of harmonic conversion for an SIS mixer.

Description of Experiment

For our experiments a tin-tin oxide-tin SIS tunnel junction was prepared on a silicon substrate using a photoresist bridge mask [4]. The junction area was roughly 10 μm^2 with a critical current density of 250 A-cm^2. The normal state resistance of the junction was 22 Ω. The unpumped tunneling I-V curves, shown in the region near the gap as the dashed curves of Figs. 1a and 1b, were very sharp. As a result, we were able to observe significant quantum effects with local oscillator frequencies as low as 18 GHz. Both fundamental mixing and harmonic mixing experiments were conducted on the same junction.

The apparatus used for mixer measurements was only slightly modified from that more thoroughly described in a previous publication [5]. The mixer was immersed in a 1.5 K helium bath. The Sn junction was placed in the E-field direction across a Ka-band waveguide. Radio frequency matching at the signal frequency was accomplished by adjusting a screw tuner and sliding backshort. Room temperature radiation was reduced by a cold 18 dB attenuator in front of the mixer block. The signal power was obtained from a carefully calibrated 36 GHz Gunn diode oscillator. The output IF signal, at 50 MHz, went through a 36 GHz choke structure to a coaxial cable leading to room temperature amplifiers.

Different LO coupling schemes were used for fundamental and harmonic mixing. For fundamental mixing, LO power from a 36 GHz klystron was coupled into the signal waveguide by means of a 10 dB directional coupler. For harmonic mixing, LO power from an 18 GHz klystron was fed to the junction through the IF line. A stub structure was used to prevent the 18 GHz LO power from propagating in the direction of the IF amplifiers. No attempt was made to match the 18 GHz drive to the junction efficiently.

Fundamental Mixing Results

Fundamental mixer results are described in detail in a previous publication [6], and are summarized here for ease of comparison to harmonic mixer results. Application of $\sim$ 1 nW of 36 GHz local oscillator power induces discernable photon-assisted tunneling steps on the I-V curve, as is shown in Fig. 1a. The steps, at voltage intervals of $\hbar\omega_{LO}/e$ (0.15 mV), are especially evident in plots of dV/dI. The third row of Fig. 1a shows the detected 50 MHz If power for fixed 36.05 GHz input signal power.

The best experimental value of the coupled mixer gain for the fundamental mixer was +4.3$\pm$1 dB (SSB) for the upper sideband. When the signal frequency was changed to 35.95 GHz without readjusting the RF matching structure, a lower sideband gain of +3.4$\pm$1 dB (SSB) was measured. The reduced conversion efficiency we attribute to the narrow-band RF matching structure used, rather than to any intrinsic junction bandwidth. It should be emphasized that both measured values of the conversion gain exceeded the limit for a classical resistive mixer of -3 dB (SSB) for configurations without significant image rejection.

Harmonic Mixing Results

For our harmonic mixer experiments the photon-assisted tunneling step width ($\hbar\omega_{LO}/e$) of 0.075 mV was nearly equal to the broadness of the gap rise. As a result, mixer performance was more classical in nature, although important quantum effects were still observable. The step structure shown in Fig. 1b is unnoticeable in the DC I-V curve, and is less dominant in dV/dI measurements than was the case for fundamental mixing. The IF signal power curve can be described by a broad overall classical structure superimposed on a somewhat smaller amplitude quantum mechanical response with 0.075 mV period. The height of the individual quantum peaks varied with LO power, although the voltage at which the peaks appeared was constant. The Bessel function-like dependence of the quantum peak amplitudes on LO power is a well known characteristic of quantum SIS mixers.

The best experimental values of the coupled conversion efficiency for the harmonic mixer were -3.2$\pm$1 dB (SSB) for one sideband, and -5.6$\pm$1 dB (SSB) for the other. While these results are significantly lower than corresponding fundamental mixer results, they are comparable to the best possible for a classical fundamental resistive mixer.

The LO coupling scheme used for harmonic mixing made measurement of the LO power available at the junction impossible. On the basis of the shape of the pumped I-V curve, the amount of absorbed LO power can be estimated at 5-10 nW. This is quite small compared with typical power levels required for Shottky mixers, but is somewhat higher than the ~ 1 nW used in the fundamental mixer experiments. It is expected that at higher frequencies, if the harmonic mixer is more strongly in the quantum regime, smaller LO power will be necessary for optimum conversion efficiency.

Conclusions

Harmonic mixing in SIS mixers has been demonstrated for an 18 GHz local oscillator dirve, with encouraging conversion efficiencies. Experience with fundamental mixers dictates that proper source impedance is critically important for maximum conversion efficiency. Improved subharmonic terminations should improve mixer performance. Higher conversion efficiencies may also be expected for higher frequency operation, where quantum effects are more important.

Acknowledgements

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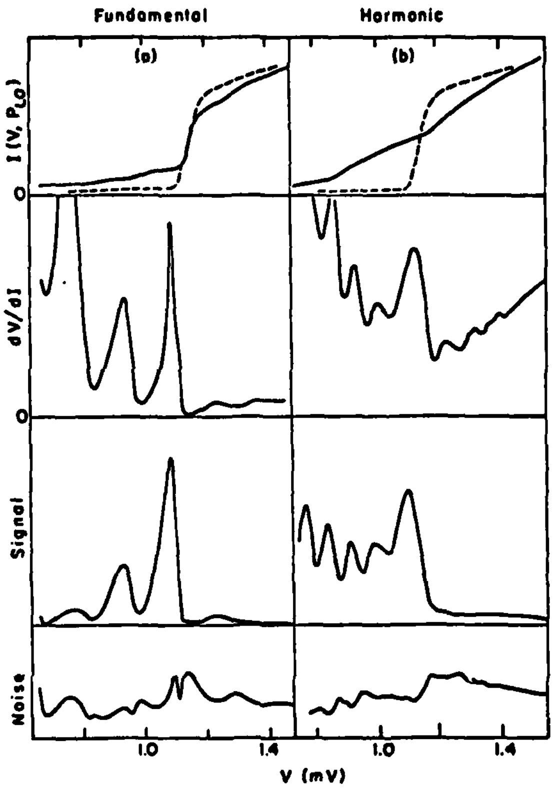

Fig. 1: Operating curves showing mixer performance. The left column (a) shows operation with a 36 GHz local oscillator, while the right column (b) describes harmonic mixing with a 18 GHz local oscillator. Different vertical scales have been employed between the two columns except for the I-V curves of the top row.